

Final Technical Report
Polar Magnetic Field Data
Principal Investigator: C. T. Russell
(10/1/98 – 09/30/01)
National Aeronautics and Space Administrator
NASA NAG5-7721

ACHIEVEMENTS

1. Technical

At this writing we have received all the CDROMs for the grant period. We have completed generating our timing tables past September 20, 2001. The calibration of the instrument has been checked for the entire mission up to the end of December 2000 and the key parameters provided to the project until the end of December 2000. These data are available to other experimenters over the web at <http://www-ssc.igpp.ucla.edu/forms/polar/>. High resolution despun data, 8 samples per sec. have been created up to November, 2000 and have been made available to the community over the world wide web. This is a new data set that was a major effort this year.

Our near term plans are to continue to provide key parameter data to the Polar project with the highest possible speed and to continue to reduce all high resolution magnetometer data and provide these data to the scientific community over the web. We have begun to produce an improved set of key parameter data with the unaliased averages of the high resolution data. In addition this new key parameter data set has an improved detrending algorithm that removes the Earth's field prior to calculating the standard deviations. We will submit all of the key parameter and high resolution data to the NSSDC. We have one important lien on our processing, because we have an improved key parameter data processing routine and it is a significant improvement, we need to redo the entire first four years Polar processing. Because of our one year backlog we cannot work at removing this lien at this time.

2. Science

The orbit of the Polar spacecraft is uniquely suited for studying the high altitude polar cusp and many of the papers published during the period of the grant concern this region. The titles of papers published in journals and books and those presented at meetings using the fluxgate magnetometer data can all be found at the website <http://www-ssc.igpp.ucla.edu/polar/polarresults.html>. Only the papers that were published or presented during the period of the grant are listed in the bibliographies below. Many of the papers published are also available on-line in their entirety at <http://www-ssc.igpp.ucla.edu/polar/papers.html>. Herein we discuss only the published papers. The numbers in square brackets [] refer to papers in the Polar bibliography below in which only the papers for the reporting period are listed. The second bibliography lists the papers presented during the reporting period.

2.1 Magnetospheric Regions

2.1.1 The Polar Cusp

The polar cusp was one of the prime targets of the Polar mission. It became immediately obvious that our models overpredicted the strength of the magnetic field in this region. The reason for this is most probably that the shape of the magnetopause near the cusp is different than assumed in the T96 model [30]. Other properties of the cusp were shown to be similar at high altitudes and at low altitudes. The location of the cusp was shown to vary with dipole tilt angle as seen by Triad and other low altitude spacecraft [22]. The cusp was found to move increasingly equatorward for increasingly southward IMF but moved only slightly for northward IMF. Further the cusp was pulled downward and duskward by the IMF By component [34]. One aspect of the cusp that had not been reported in the low altitude data was that the component of the solar wind dynamic pressure directed into the cusp controls the thermal pressure of the cusp plasma [53]. Thus the tilt angle of the cusp and the solar wind dynamic pressure jointly determine the cusp pressure. We have also compared the properties of the cusp with those expected from models and simulations [52] including a case study of the cusp under northward IMF conditions [65]. We have also studied the ion cyclotron waves of the cusp [62] and the behavior of ion conics [66].

2.1.2 Field-Aligned Currents

The strength and the pattern of field-aligned currents seen at low altitudes was quickly confirmed at high altitude by Polar. It was also shown that the strength of these currents is controlled by the north-south orientation of the IMF and not by the solar wind dynamic pressure [45]. This is particularly important to the ion outflow process and the interpretation of these observations.

2.1.3 Plasma sheet

The study of the plasma sheet has been led by team member C. Cattell and her colleagues at University of Minn. They showed that there were large parallel electric fields in the plasma sheet boundary layer, calculated the velocity of solution wave packets in this boundary [21] and showed that the large Poynting flux there can power the aurora [47]. More recent work has concentrated on the large flux of Alfvén waves [49] and the large electric fields in the plasma sheet [54]. Most recently she has examined solitary waves at the plasma sheet boundary [64].

2.2 Magnetospheric Activity

2.2.1 Storms

Soon after the initial data were studied it was clear that the ring current could be monitored by studying Polar data as it crossed the polar cap. By studying the conditions leading up to the September 24, 25 magnetic storm we showed that it was steady southward and not oscillating fields that led to the build up of the ring current [43]. Also by comparing with FAST measurements we were able to show that strong field-aligned currents lead to ion mass ejection and not dynamic pressure fluctuations [48]. The ring current was shown to be quite insensitive to the dynamic pressure of the solar wind [46]. On the day the solar wind nearly disappeared the

pre-existing ring current remained unchanged. As a follow on to the study of the September 24, 25, 1998 storm, we also examined the potential drop across the polar cap as a function of the IEF for a number of very large storms and demonstrated that the polar cap potential drop saturated [56]. This has extremely important implications for the formation of the ring current. We also examined the magnetopause and magnetotail during the May 4, 1998 storm [59].

2.2.2 Magnetospheric Compressions

The magnetosphere becomes compressed when the solar wind dynamic pressure increases. Interesting dynamics occurs when the increase occurs rapidly as across an interplanetary shock. One such occurrence was on September 24, 1998 when the first evidence for an ionospheric mass ejection was discovered [24,25]. Part of the signature was due to the motion of the spacecraft in a layered plasma [25] and part was due to centrifugal acceleration [42]. Some was due to the acceleration of ionospheric plasma and this acceleration may be controlled by the Poynting flux in field-aligned currents [48]. Studies of the May 4, 1998 storm showed that the solar wind was on occasion strong enough to compress the magnetosphere inside Polar's apogee. In fact even the bow shock moved inside Polar on this day [32]. Studies in support of the September 24, 25, 1998 storm also showed that the multiple spacecraft of the ISTP program could accurately determine the shock speed, orientation and strength [50]. This study has been continued along two separate paths. We have followed the preliminary reverse impulse triggered by these shocks and shown them to be good probes of the density of the magnetosphere, just like seismic signals in the Earth [59]. Also we have studied the compressional response of the magnetosphere over the entire volume of the magnetosphere [60].

2.2.3 Waves

Our study of waves concentrated on their energy source. In one case a northward turning IMF apparently triggered a field-aligned resonance. On the day the solar wind nearly disappeared the shock weakened and moved outward from the magnetosphere. Simultaneously the wave level in the magnetosphere dropped [46]. We attribute this to the lessening of upstream wave activity and the subsequent reduction in the buffeting of the magnetosphere. We have also as discussed above studied the occurrence of ion cyclotron waves in the cusp [62].

2.2.4 Substorms

Even in its initial orbit Polar could contribute to the study of substorms. These observations were obtained both in the high altitude polar cap where the field strength and orientation depend on the shape of the magnetopause and on field lines connected to the auroral oval [51]. We expect increasingly detailed studies of substorms as the line of apsides approaches the magnetic equator.

3. Processes

3.1 Reconnection

Arguably the most important process in energizing the magnetosphere is reconnection and this process has been the subject of intense study by the Polar community. Perhaps the greatest effort has been expended on an encounter of Polar with the high latitude magnetopause on May 29, 1996 when the IMF was northward. We established the overall geometry of the magnetosphere during this event with our data and MHD models and showed that it represented an example of post-cusp reconnection. By comparing with Interball data we showed that the same geometry persisted for several hours in local time and in universal time. Working with J. D. Scudder we showed that the Walen relation across rotational discontinuities was as predicted for electrons but that the observed ion behavior differed from the “standard” theory [28]. We also showed that the reconnection site varies with the IMF B_y and B_z [34]. We also provided an alternate interpretation of particle distributions that had been claimed as indicating that the reconnection of parallel magnetic fields could occur [37]. This alternate explanation preserves the classical understanding of reconnection.

3.1.1 Particle Acceleration

One of the most controversial areas of work on Polar concerns the role of the polar cusp in the acceleration of highly energetic particles near the Polar cusp. We have helped both sides in this controversy present their cases, both for this mechanism [26] and against it [36,63]. We have also been studying the auroral acceleration processes in comparison of Polar and FAST data [61].

3.2 Magnetospheric Models

3.2.1 Comparisons with Magnetic field Models

Some of the main workhorses of magnetospheric research have been the series of magnetic field models of Tsyganenko. One of the first tasks we undertook, both independently and in conjunction with Tsyganenko, was to compare Polar data with this model. We found that near the polar cusp the model overestimated the magnetic field strength possibly due to a difference between the actual shape of the magnetopause and that assumed in the model in the region of the cusp [30]. We found that the model does not respond as strongly to a dynamic pressure increase as observed [10]. We found that field-aligned current sheets are much more narrow than predicted in the models [10], and we found that the perturbation magnetic field in the inner magnetosphere has a strong noon-midnight and dawn dusk asymmetry [27]. We have also compared the Tsyganenko Field model with predictions from MHD [57].

3.2.2 MHD Simulations

Since MHD simulations are increasingly being used to understand and interpret magnetospheric behavior it is important to validate these models. First we were able to show at a sensitive region of the magnetosphere that the MHD model accurately predicts the magnetic and plasma structure including the boundary location and currents. We showed that the MHD model was successful in predicting the time evolution of the magnetosphere when accurate time varying boundary conditions were employed. We also showed that some current sheets were much thinner than predicted by the MHD model. As noted above the predictions of MHD models have

been compared with the empirical model of Tsyganenko [57] and made a detailed study of the cusp on April 11, 1997 when the IMF was strongly northward [65].

4. Summary Table of presentations by FY

Table 1. Summary of Presentations and Publications by Year

Papers by Type	FY 96	FY 97	FY 98	FY 99	FY 00	FY 01
Presentations	2	51	33	52	37	42
First Author Pub.	1	4	6	4	11	2
Co-author Pub.	0	1	8	7	6	5

Papers in Journals and Books using Polar Magnetometer Data (10/1/98 – 10/1/2001)

19. N. C. Maynard, W. J. Burke, D. R. Weimer, F. S. Mozer, J. D. Scudder, C. T. Russell and W. K. Peterson, Dayside electrodynamics observed by Polar with northward IMF, in Geospace Mass and Energy Flow: Results from the International Solar-Terrestrial Physics Program, 13-23, AGU, Washington DC, 1998.
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22. X-W. Zhou, C. T. Russell, G. Le, S. A. Fuselier and J. D. Scudder, The polar cusp location and its dependence on dipole tilt, Geophys. Res. Lett., **26**, 429-432, 1999.
23. C. Whipple, D. L. Starr, J. S. Halekas, J. D. Scudder, R. D. Holdaway, J. B. Faden, P. Puhl-Quinn, N. C. Maynard and C. T. Russell, Magnetospheric electric fields from ion data, Geophys. Res. Lett., **26**, 1561-1564, 1999.
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26. T. A. Fritz, J. S. Chen, R. B. Sheldon, H. E. Spence, J. F. Fennell, S. Livi, C. T. Russell and J. S. Pickett, Cusp energetic particle events measured by POLAR spacecraft, Phys. Chem.

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28. J. D. Scudder, P. A. Puhl-Quinn, F. S. Mozer, K. W. Ogilvie, and C. T. Russell, Generalized Walén tests through Alfvén waves and rotational discontinuities using electron flow velocities, J. Geophys. Res., 104, 19,817-19,833, 1999.
29. C. T. Russell, Magnetic stress in solar system plasmas, Aust. J. Phys., 52, 733-751, 1999.
30. N. A. Tsyganenko, and C. T. Russell, Magnetic signatures of the distant polar cusps: Observations by Polar and quantitative modeling, J. Geophys. Res., 104, 24,939-24,955, 1999.
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34. X-W. Zhou, C. T. Russell, G. Le, S. A. Fuselier and J. D. Scudder, Solar wind control of the polar cusp at high altitude, J. Geophys. Res., 105, 245-251, 2000.
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43. C. T. Russell, G. Lu and J. G. Luhmann, Lessons from the ring current injection during the September 24, 25, 1998 storm, Geophys. Res. Lett., 27, 1371-1374, 2000.
44. E. Zesta, H. J. Singer, D. Lummerzheim, C. T. Russell, L. R. Lyons and M. J. Brittnacher, The effect of the January 10, 1997, Pressure pulse on the magnetosphere-Ionosphere current system, in Magnetospheric Current Systems, AGU Geophys. Mono., 118, 217-226, American Geophysical Union, Washington, D.C., 2000.
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56. C. T. Russell, J. G. Luhmann, and G. Lu, Nonlinear response of the polar ionosphere to large values of the interplanetary electric field, J. Geophys. Res., 106, 18,495-18,504, 2001.
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Presentations at Meetings (10/1/1998 – 10/1/2001)

87. J. A. Newbury, C. T. Russell, M. Gedalin, F. S. Mozer and J. Wygant, Fine scale electric and magnetic bow shock structure: POLAR observations, presented at the Fall AGU meeting, (abstract) *Eos, Trans. AGU*, 79(45), Fall Meeting Suppl., F713, 1998.
88. S. P. Slinker, J. A. Fedder, J. G. Lyon, C. T. Russell, R. Fenrich, J. G. Luhmann and N. A. Tsyganenko, Modeling POLAR-MFE measurements by MHD simulations: comparisons and interpretations, presented at the Fall AGU meeting, (abstract) *Eos, Trans. AGU*, 79(45), Fall Meeting Suppl., F752, 1998.
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90. J. H. Clemmons, F. S. Mozer, H. Laakso, R. F. Pfaff Jr., P. J. Chi and C. T. Russell, Electric ULF waves measured by the Polar spacecraft, presented at the Fall AGU meeting, (abstract) *Eos, Trans. AGU*, 79(45), Fall Meeting Suppl., F767, 1998.
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